



Robonaut 2 - Activities of the First Humanoid Robot on the International Space Station

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Overview



Robonaut Motivation

GM Relationship

Robonaut Evolution

Robonaut 2 (R2) Capabilities

Preparing for ISS

Journey to Space

On Board ISS

Future Activities



Robonaut Motivation

Capable Tool for Crew

- Before, during and after activities

Share EVA Tools and Workspaces.

- Human Like Design

Increase IVA and EVA Efficiency

- Worksite Setup/Tear Down
- Robotic Assistant
- Contingency Roles

Surface Operations

- Near Earth Objects
- Moon/Mars

Interplanetary Vehicles

Telescopes



Astronaut Nancy Currie works with 2 Robonauts to build a truss structure during an experiment.



Robonaut Development History

1998

- Subsystem Development
- Testing of hand mechanism

1999

- Single Arm Integration
- Testing with teleoperator

2000

- Dual Arm Integration
- Testing with dual arm control

2001

- Waist and Vision Integration
- Testing under autonomous control

2002

- R1A Testing of Autonomous Learning
- R1B Integration

2003

- R1A Testing Multi Agent EVA Team
- R1B Segwanaut Integration

2004

- R1A Autonomous Manipulation
- R1B 0g Airbearing Development

2005

- DTO Flight Audit
- Begin Development of R1C

2006

- Centaur base
- Coordinated field demonstration



ROBONAUT

Fall 1998



ROBONAUT

Fall 1999



ROBONAUT

Fall 2000



ROBONAUT

Fall 2001



ROBONAUT

Fall 2002



ROBONAUT

Fall 2003



ROBONAUT

Fall 2004



ROBONAUT

Fall 2006

GM's Motivation



Why did GM originally come to us?

- World wide search for experienced development partner
- Looking for a robot that could do work
- Identified Robonaut development at JSC as a good match in terms of common goals and maturity level

GM Goals

- Exploit “Humanoid Dexterity”
- Automate “Non Traditional” Applications
- Ergonomically difficult tasks

R2 – Successful Government-Industry Collaboration



NASA and GM came together

- In early 2007, GM and NASA began the R2 development
- GM embedded 7 engineers onsite at JSC, working with equal numbers of NASA and Oceaneering Space Systems (OSS) Engineers
- Formed a “Badgeless” team



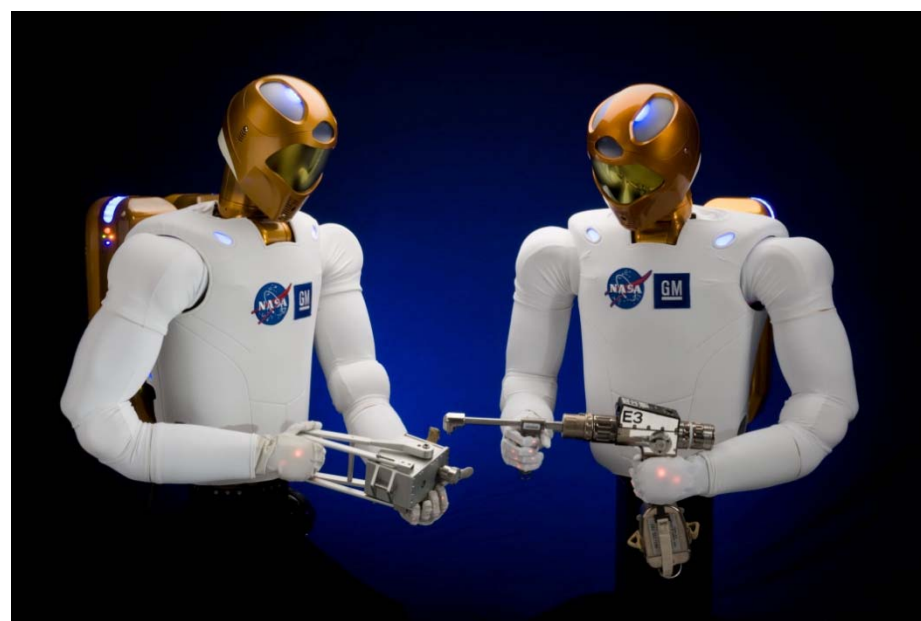
Robonaut Series

Robonaut 1 (R1)



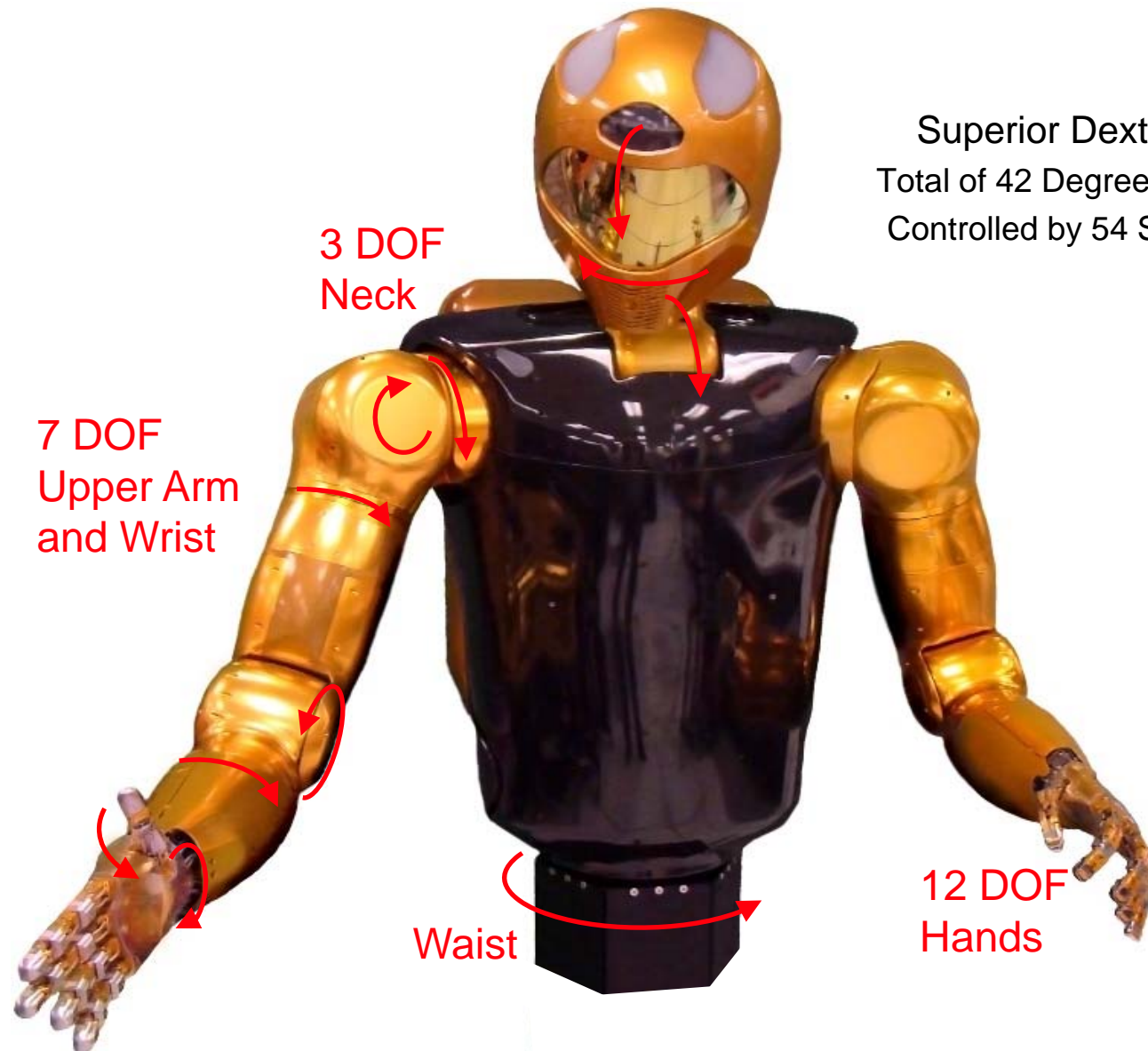
Excellent

Robonaut 2 (R2)



Better

Robonaut 2 Introduction



Superior Dexterity
Total of 42 Degrees of Freedom
Controlled by 54 Servo Motors

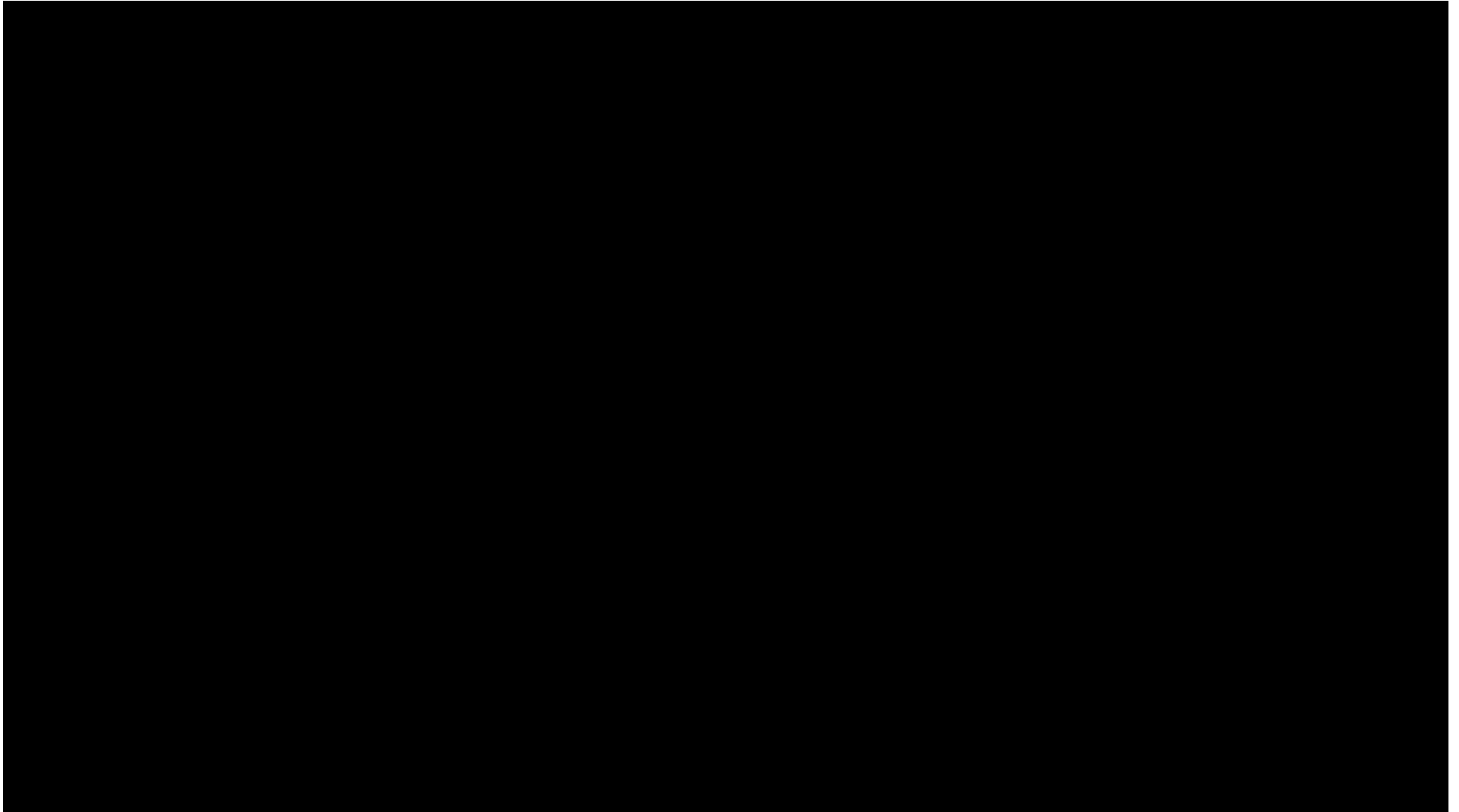
3 DOF
Neck

7 DOF
Upper Arm
and Wrist

Waist

12 DOF
Hands

Robonaut 2 Introduction



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Hand Dexterity



4 DOF Thumb

Dexterous fingers

Grasping fingers

Approaching human joint
travel

High friction grip surface

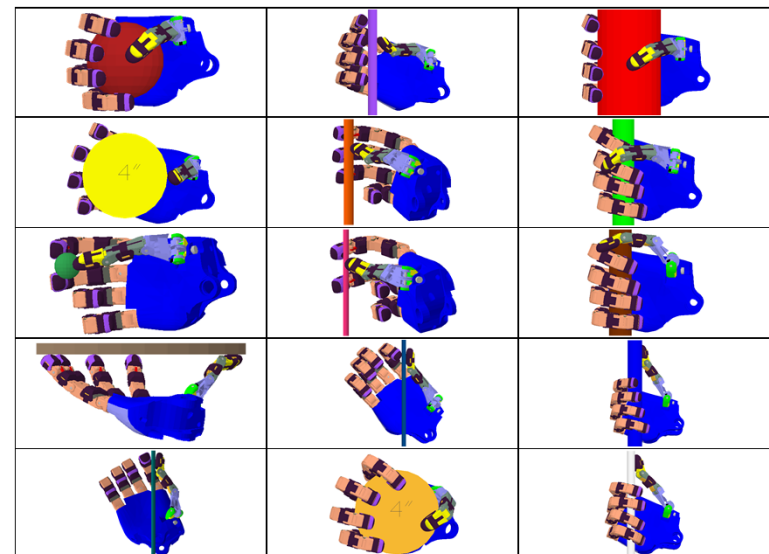
Fine motion

Tendon Tension

Wide range of grasps

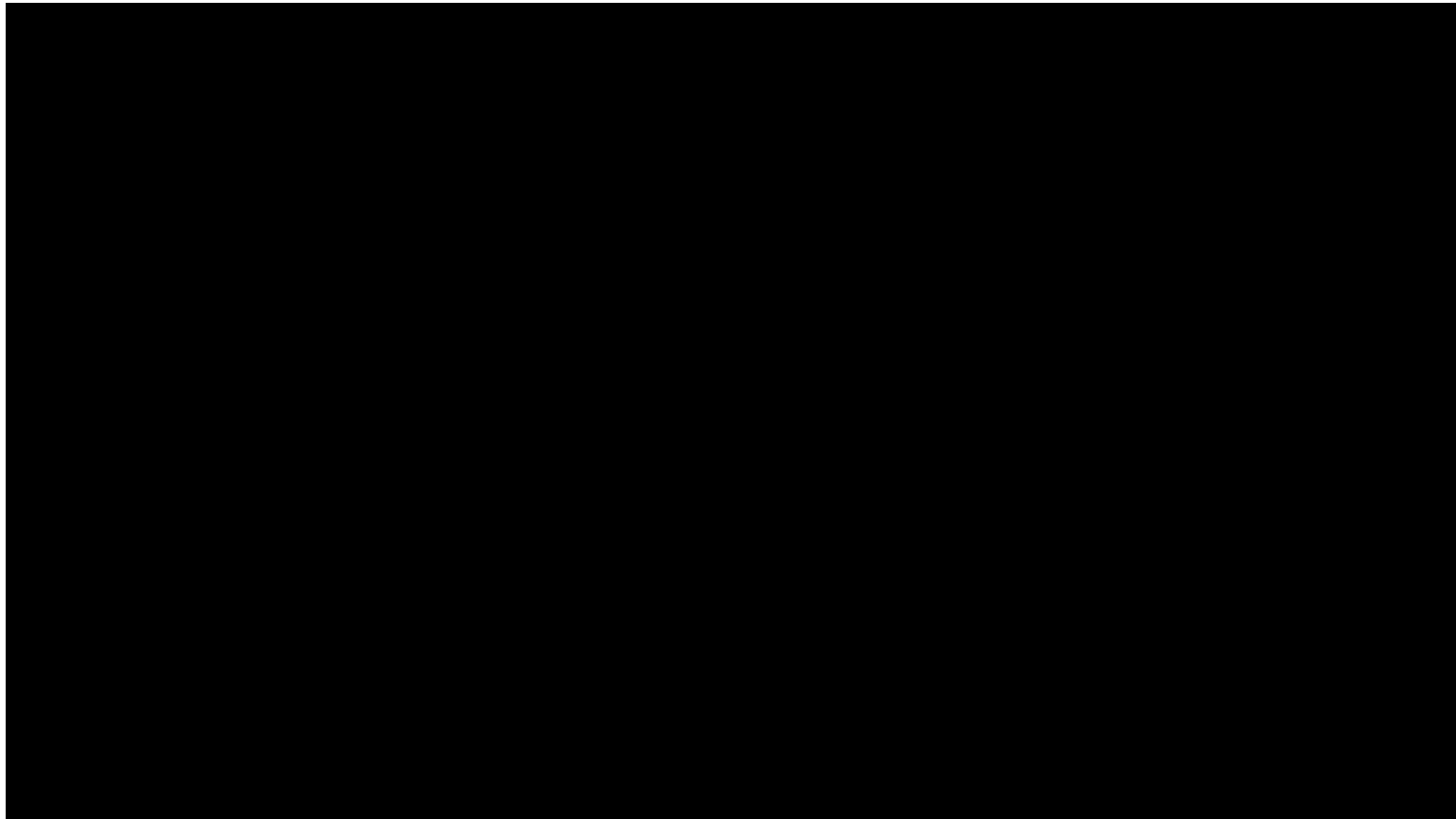


Human Like Grasps: Pen



Cutkosky Grasps

Finger Dexterity – Knob Turn



Finger Impedance Control



Tactile System

Extremely Small

Integrated Load Cells

6 Axis

Up to 14 per Hand

Serialized Data

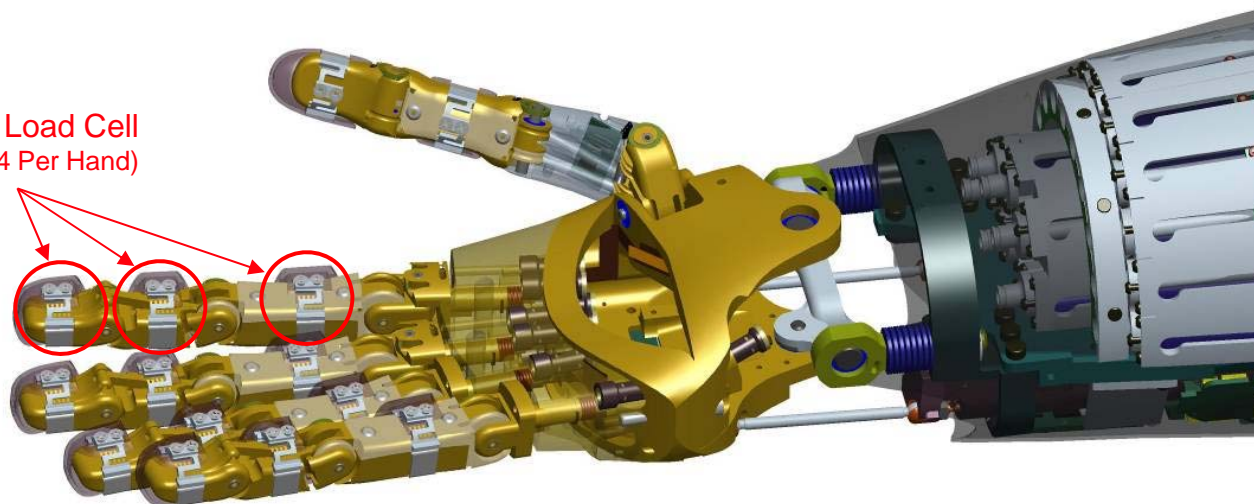
Gram sensitive

US Patent 7,784,363 B2



Load Cell

Custom Six Axis Load Cell
(Up to 14 Per Hand)



Finger Haptics



Arm Control



Series Elastic Control

- Embedded Springs
 - US Patent App. 20100145510
- High resolution absolute position sensing
- Joint level torque control
 - 10Khz loop
- Variable compliance



Torsional Spring

Modular Joint Electronics

- Highly integrated
- Redundant processing
- Local A/D
 - Noise reduction



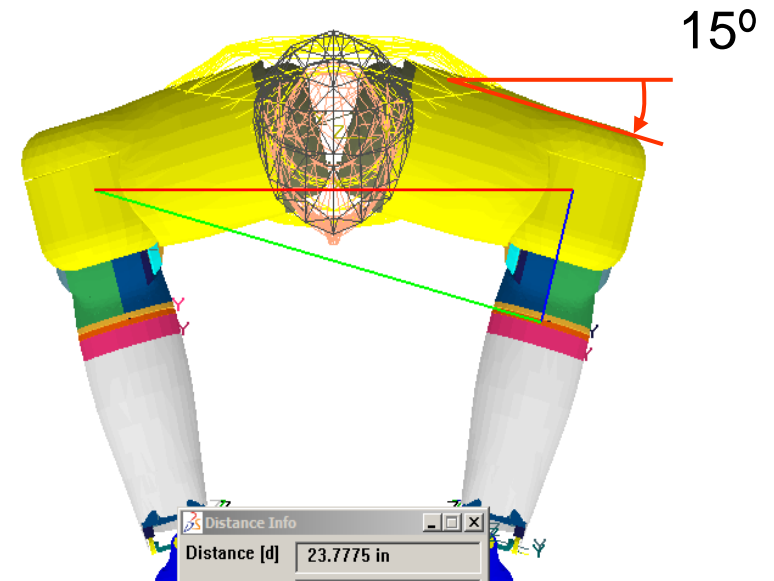
Plug-in SuperDriver

Workspace



Dual Arm Workspace

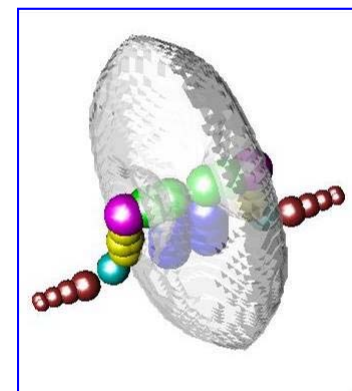
- Maximized through Arm Placement
- 15 degree shrug angle
- Increases workspace in front of Robot -



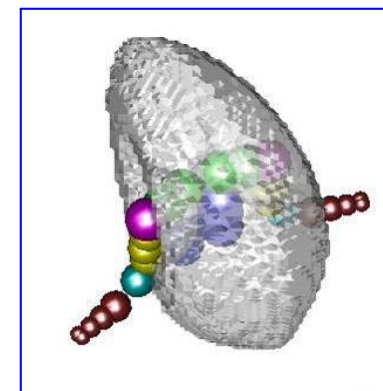
Shoulders with Shrug

Body Mobility

- Waist Degree of freedom
- Extend dual arm workspace over 360 degrees



No Shrug



Shrug

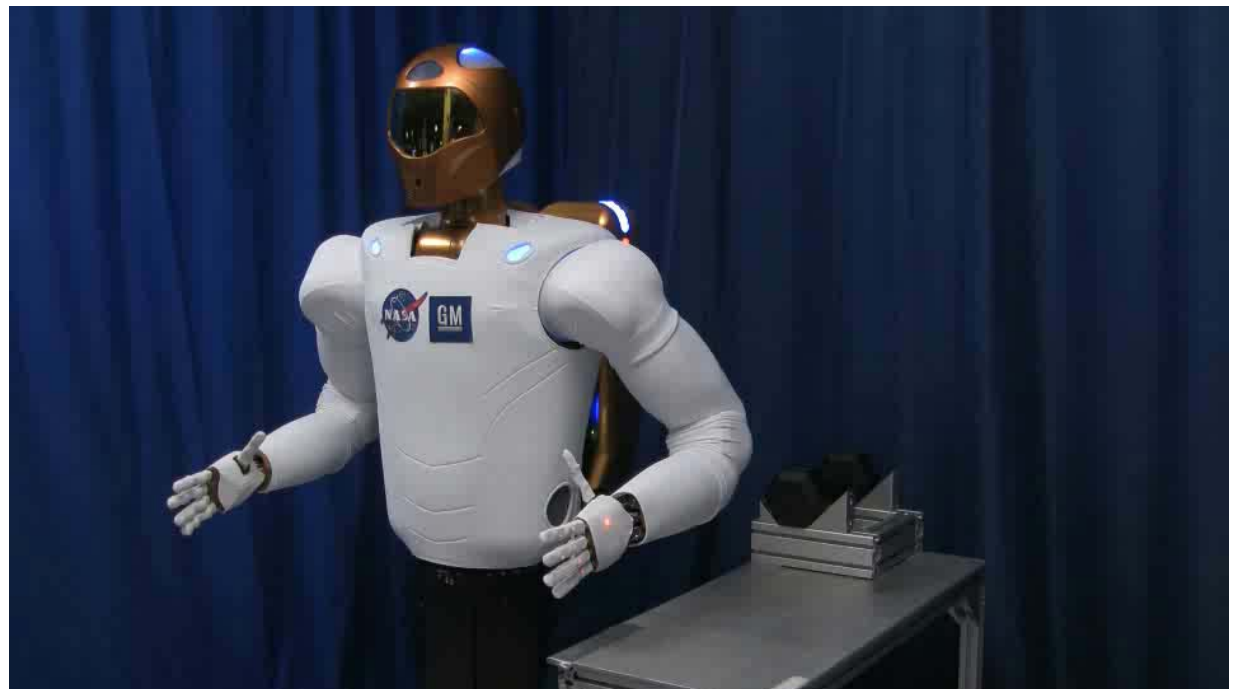
Strength



Minimum 20 lb lift capability

Exceeds human endurance at human
strength

Differentiator



Neck/Head

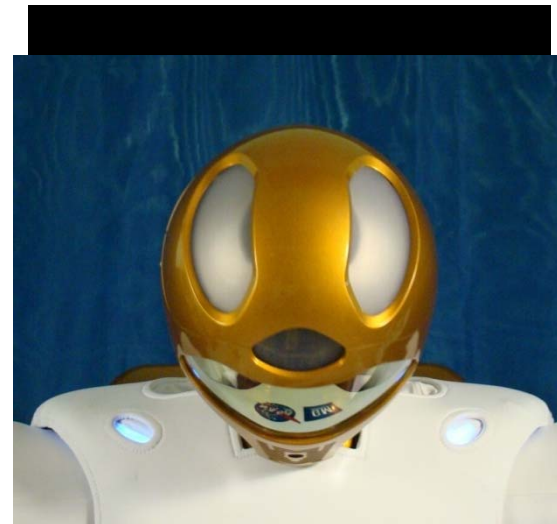


Neck

- Three Degree of Freedom
- Inspired by Human Spine
 - Double pitch joints
- Enhanced viewing close to body

Head Sensor System

- Workspace visual data
- Mounted on Atlas of Neck
 - Stereo high resolution Cameras
 - Infrared camera for growth
 - Auxiliary lighting



Neck Photo

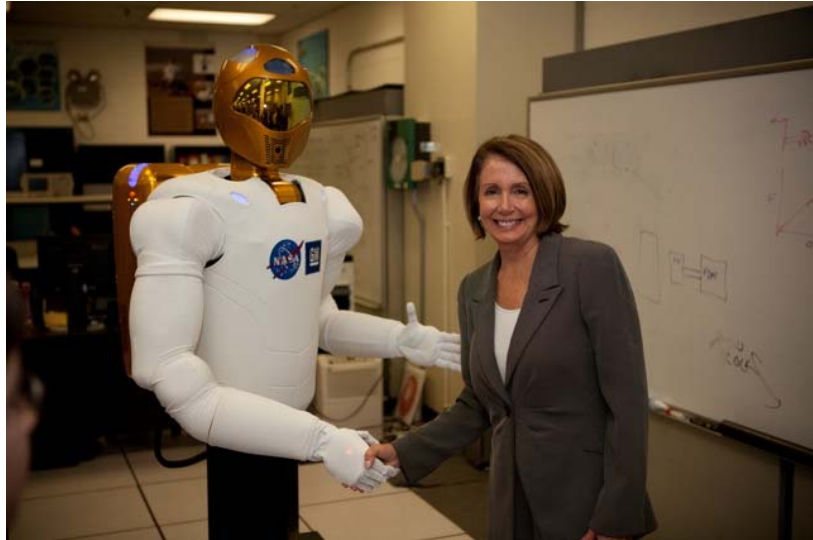
Human Interaction

Size

- Smaller than R1
 - Internal wiring – 16 conductors
 - 32” wide
- Comparable to human
- Soft skin with padding

Safety

- Force limiting
- Unintentional Contact Sensing
- Multi-level Sensors
 - Position
 - Force/Torque
 - Cross checks
 - Heartbeats



Designed to Interact with People



Force Limited at Multiple Levels

Force Control

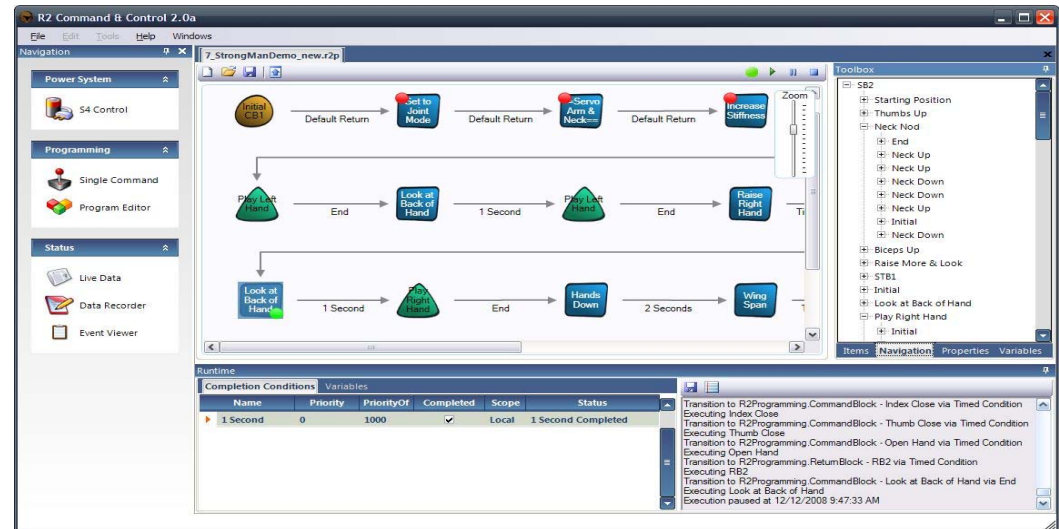


Human Interface - Controller



User Interface

- Menu based
- Startup with minimal typing
- Easy to use
 - Even I can run the robot
 - I have even built scripts
 - Cady and Paolo



Skills toolbox

- Primitive Blocks
- Controller
 - Zero-g motion
 - Cartesian control
 - Stiffness control
- Predefined grasps
 - Drill
 - Multi-Layer Insulation



Semi-experienced R2 Operator

Human Interface - Teleoperation



Teleoperator Interface

- Intuitive
- Immersive (very)
- Investigative

Programming Tool

Flexible Interface

- Unstructured tasks



Washington DC Experience

Flexible Material Application



The Space Blanket

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R2 on Space Station



Putting A Robot On ISS-IVA Will Take Us A Long Way Towards Maturation

- Space Vehicle(s)
- Micro-gravity
- EMI/Radiation environment
- Crew Interaction

Earn Stripes

- Task board operations
- Low risk IVA crew tasks
- Beyond

Engage ISS Inspection and Maintenance Community

Education

Public Relations



Preparing For Shuttle Launch and ISS



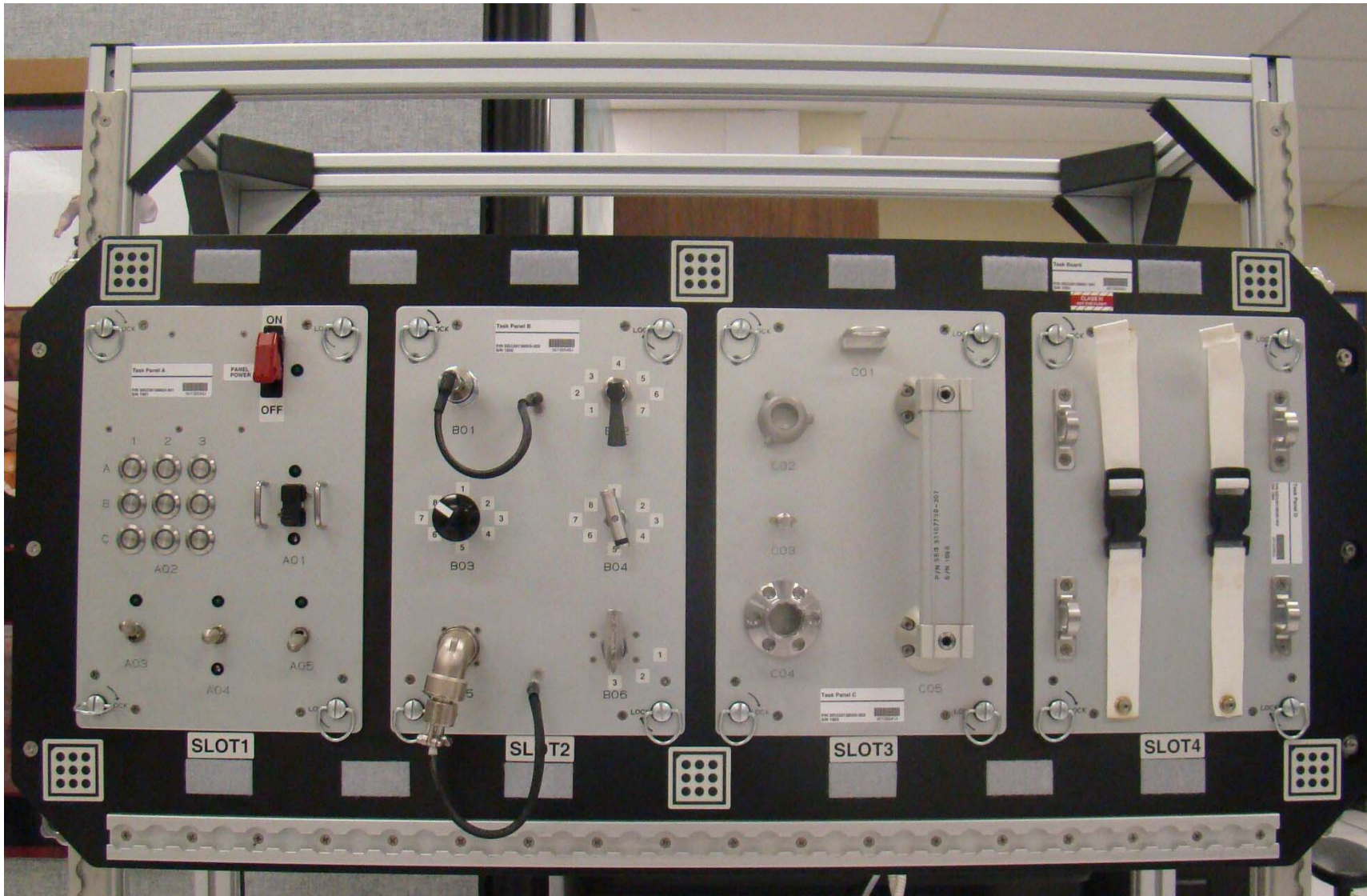
Audits

- Materials
- Vibration
- Acoustics
- Grounding
- Safeties
- Video/Comm

Development Testing

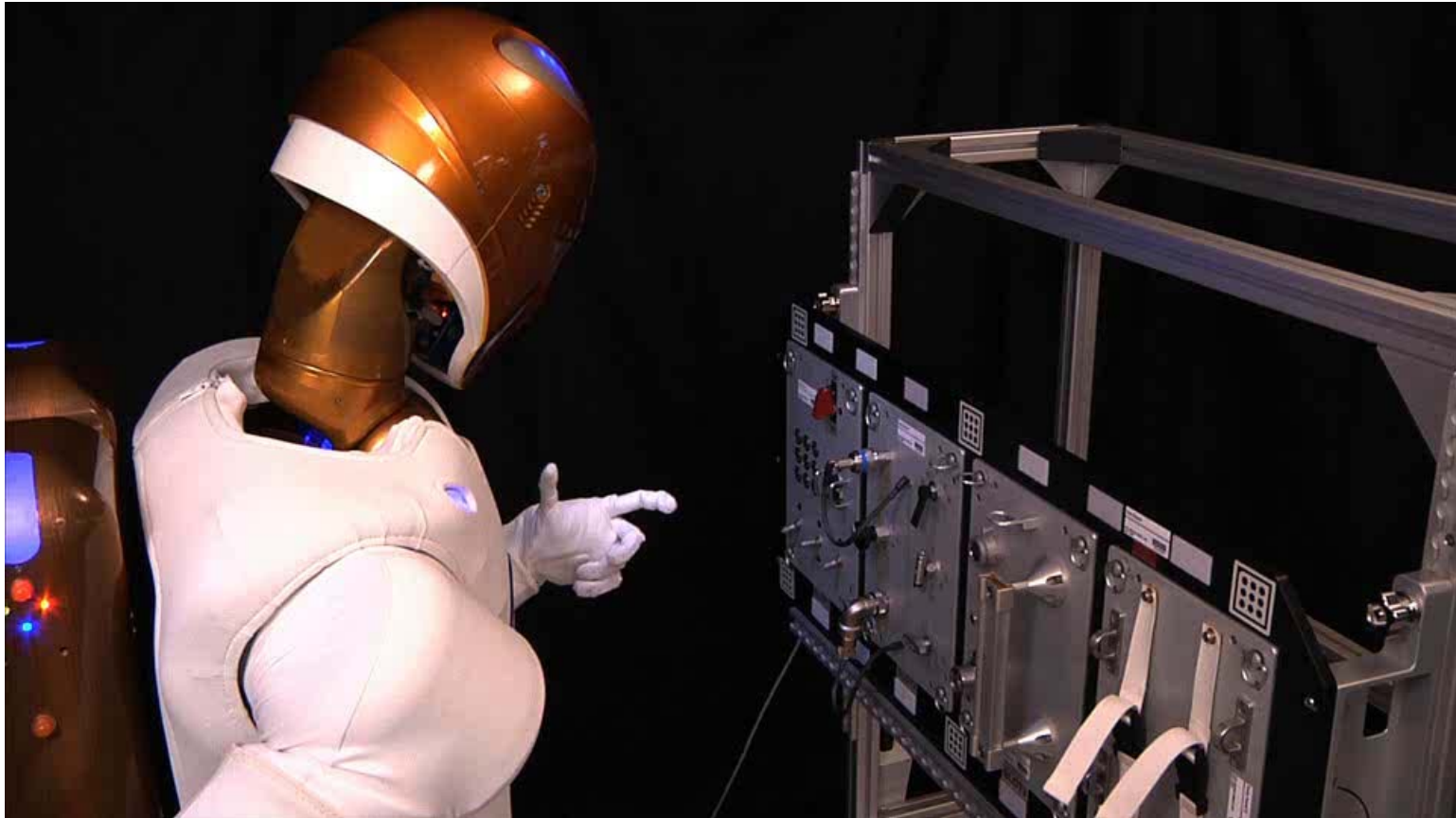
- Radiation
- EMI
- Power quality
- Acoustics
- Vibration

R2 on Space Station



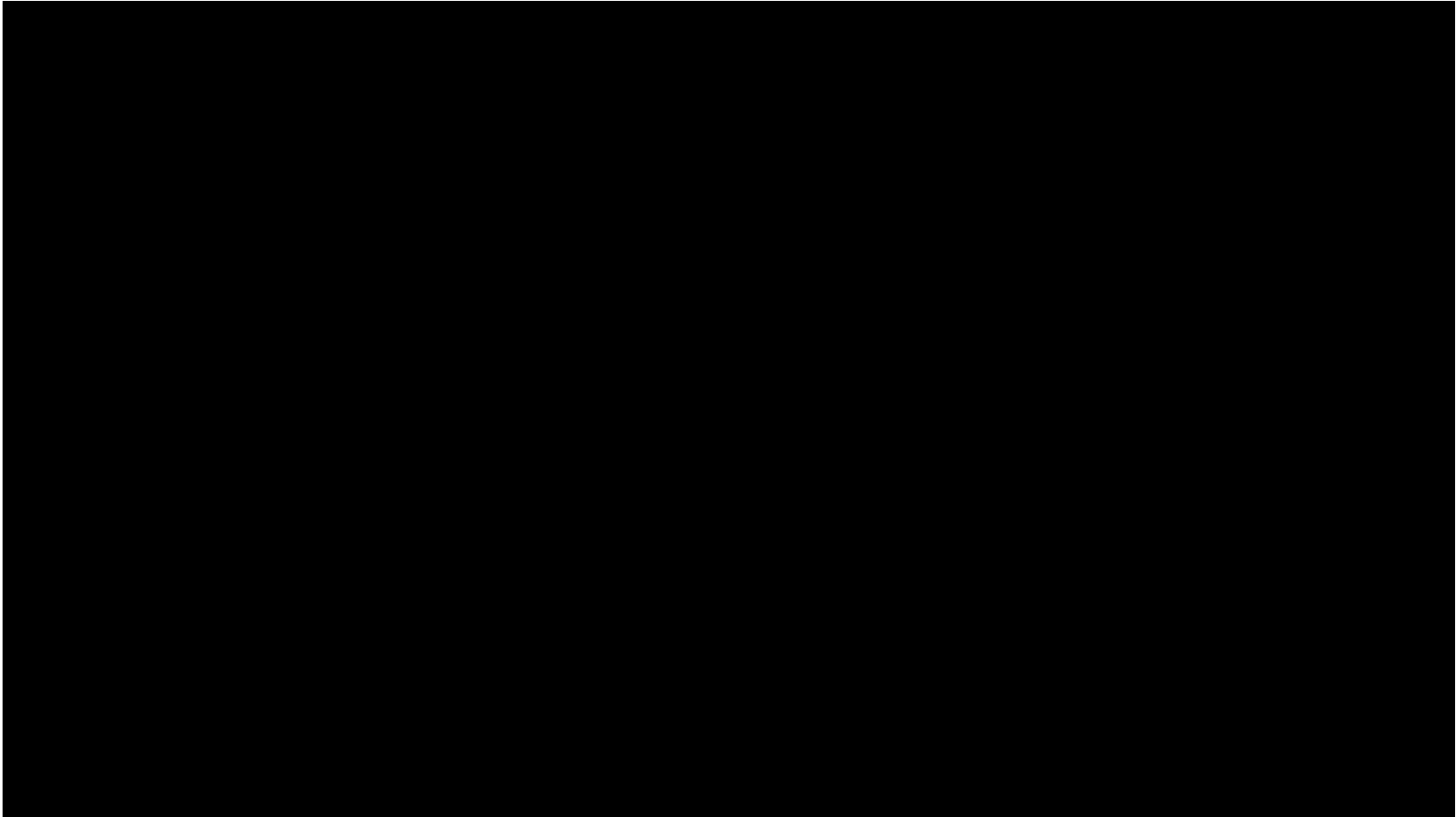
ISS Modular Task Board

Practicing for ISS – Task Board Development

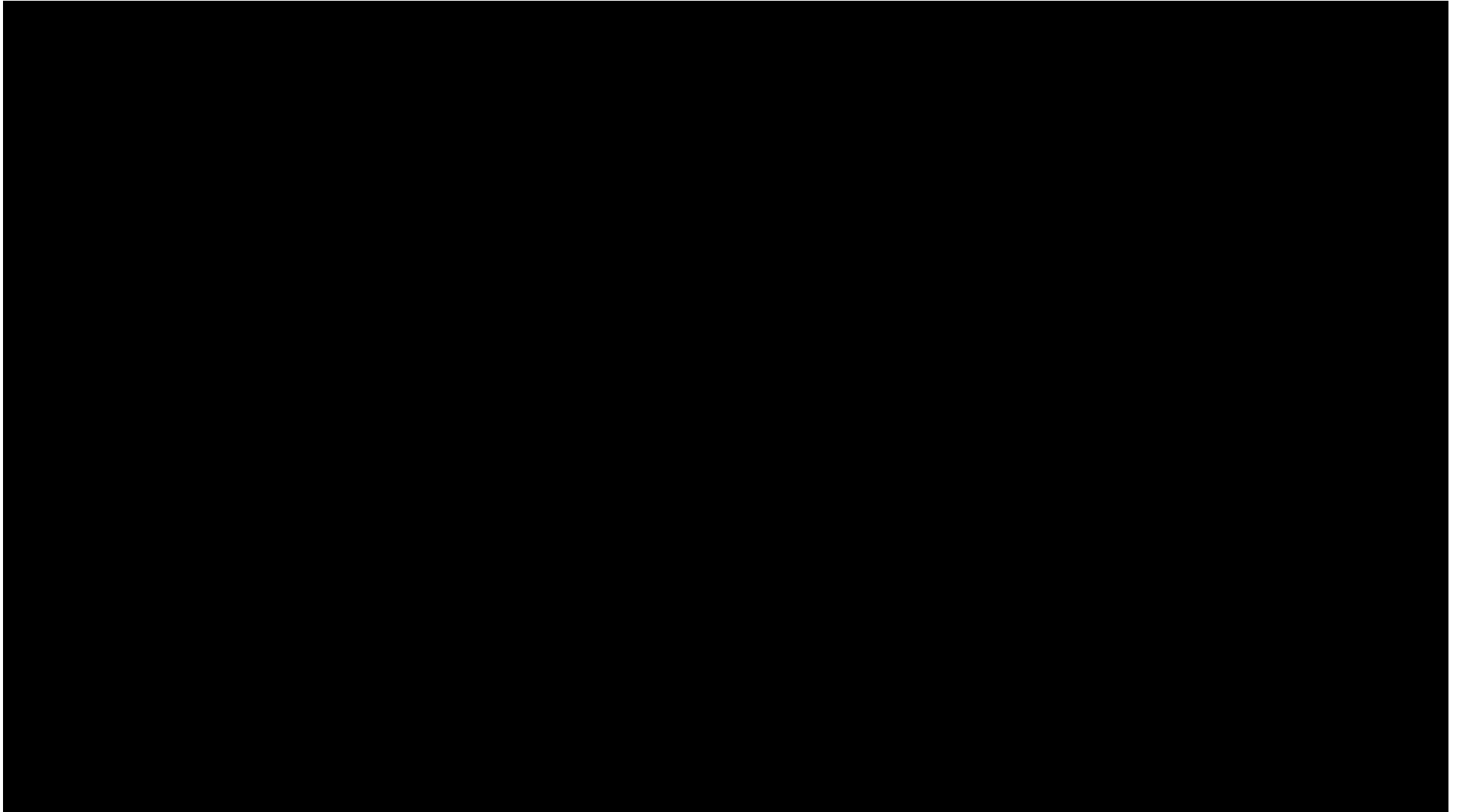


R2 Ground Unit

Crew Training – Teleoperation Training



Journey to Space



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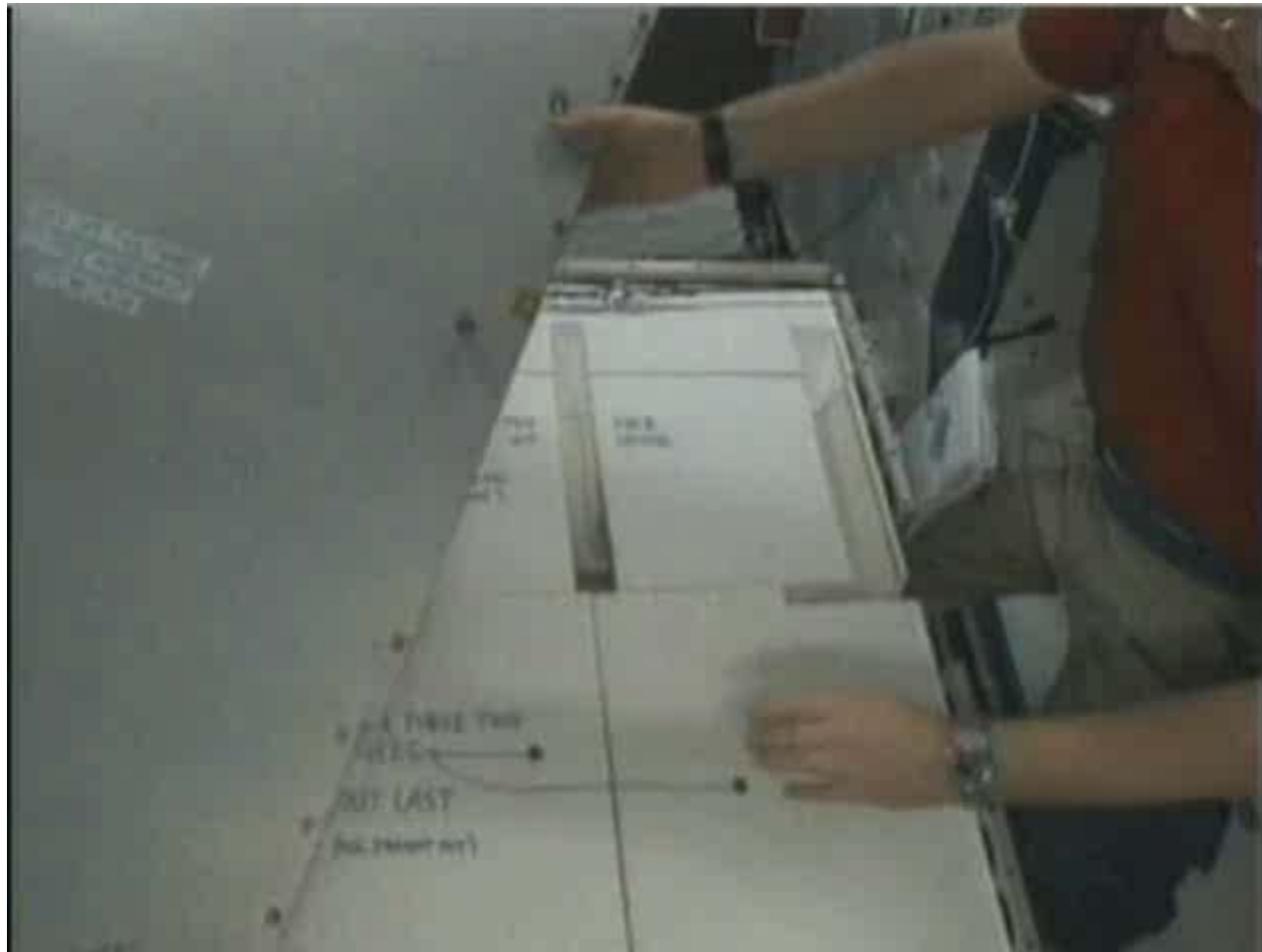
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R2 Unpack Video



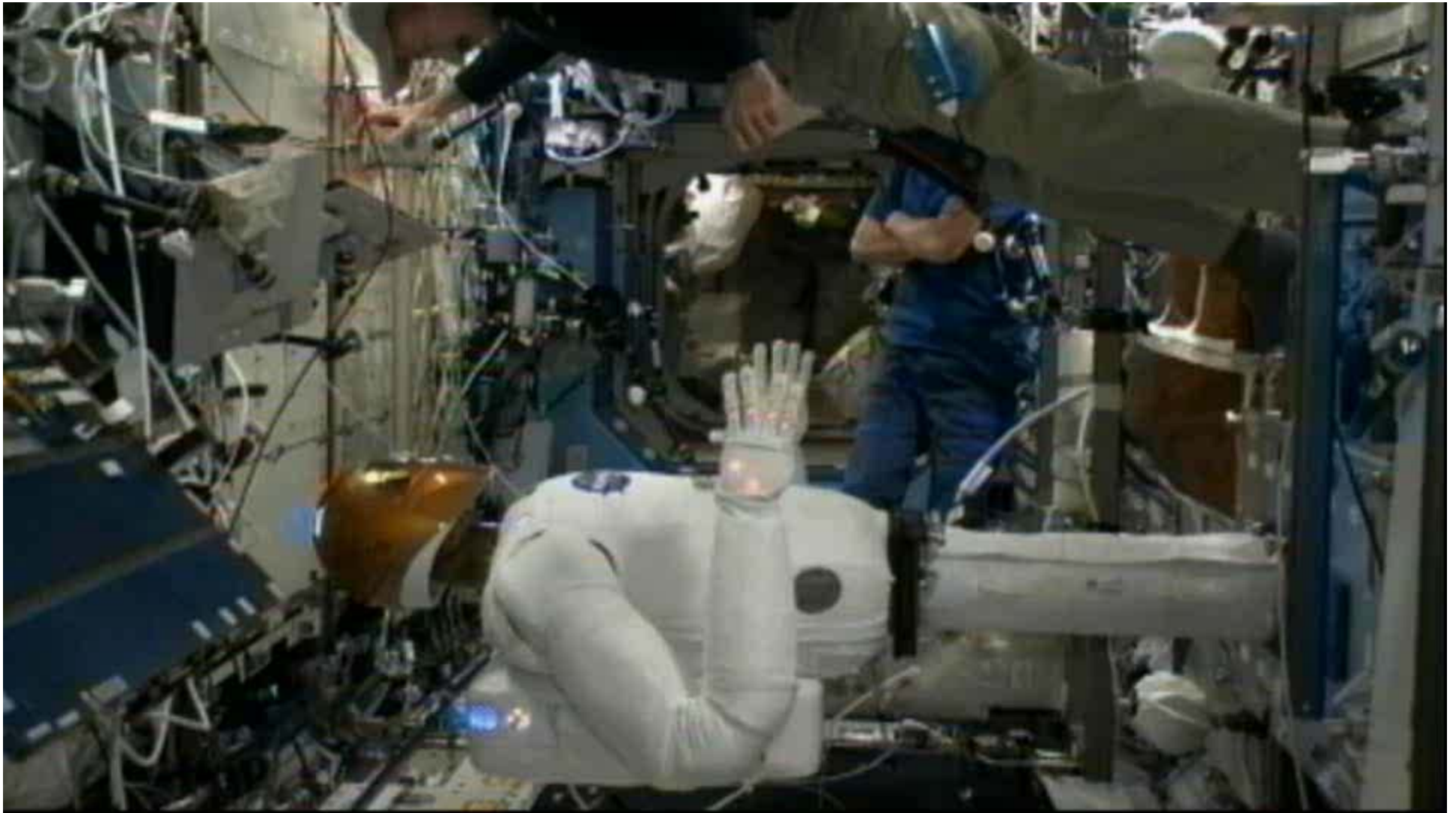
R2 Setup on ISS – Power Soak



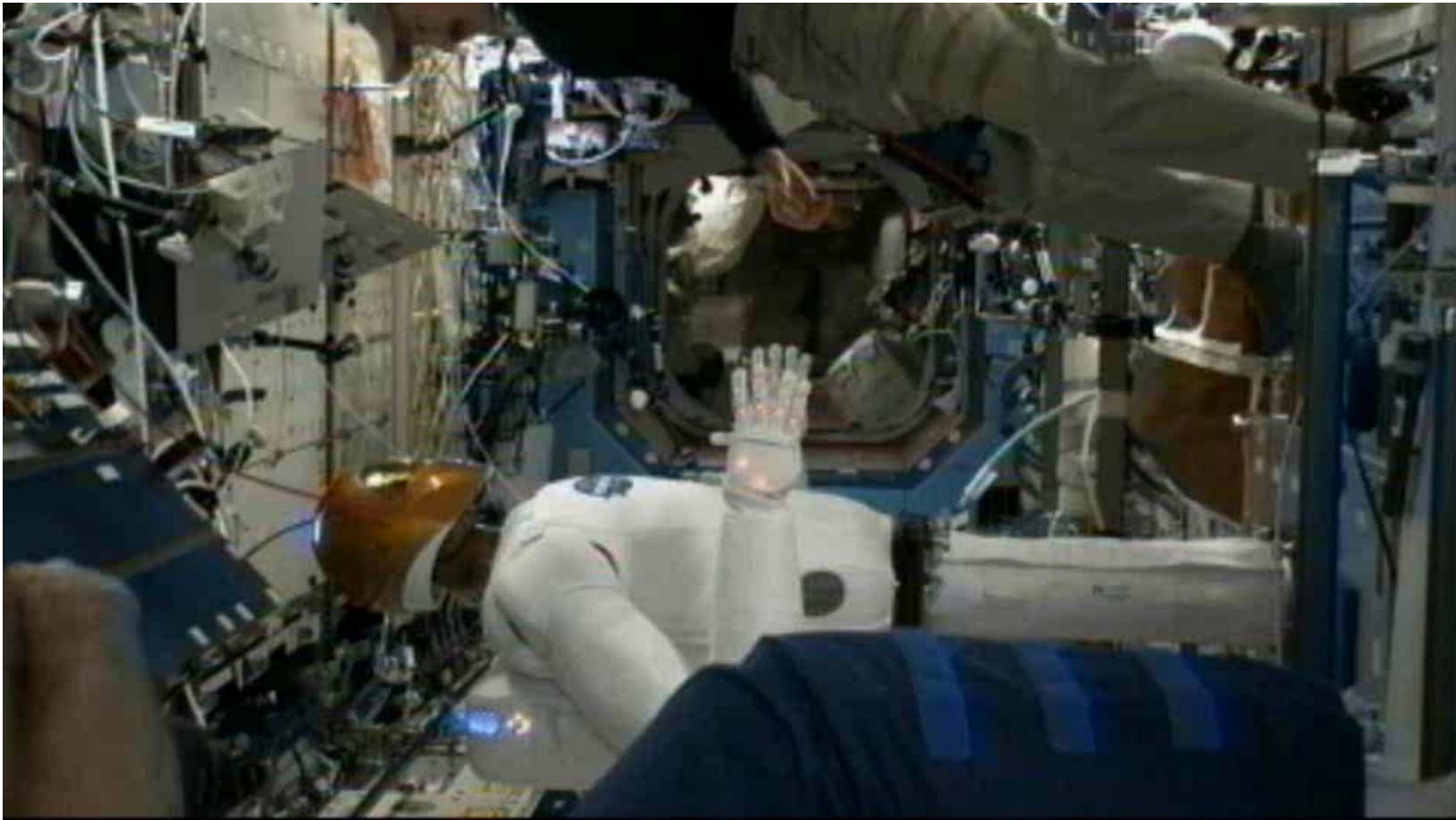
First Humanoid Robot In Space - Motion



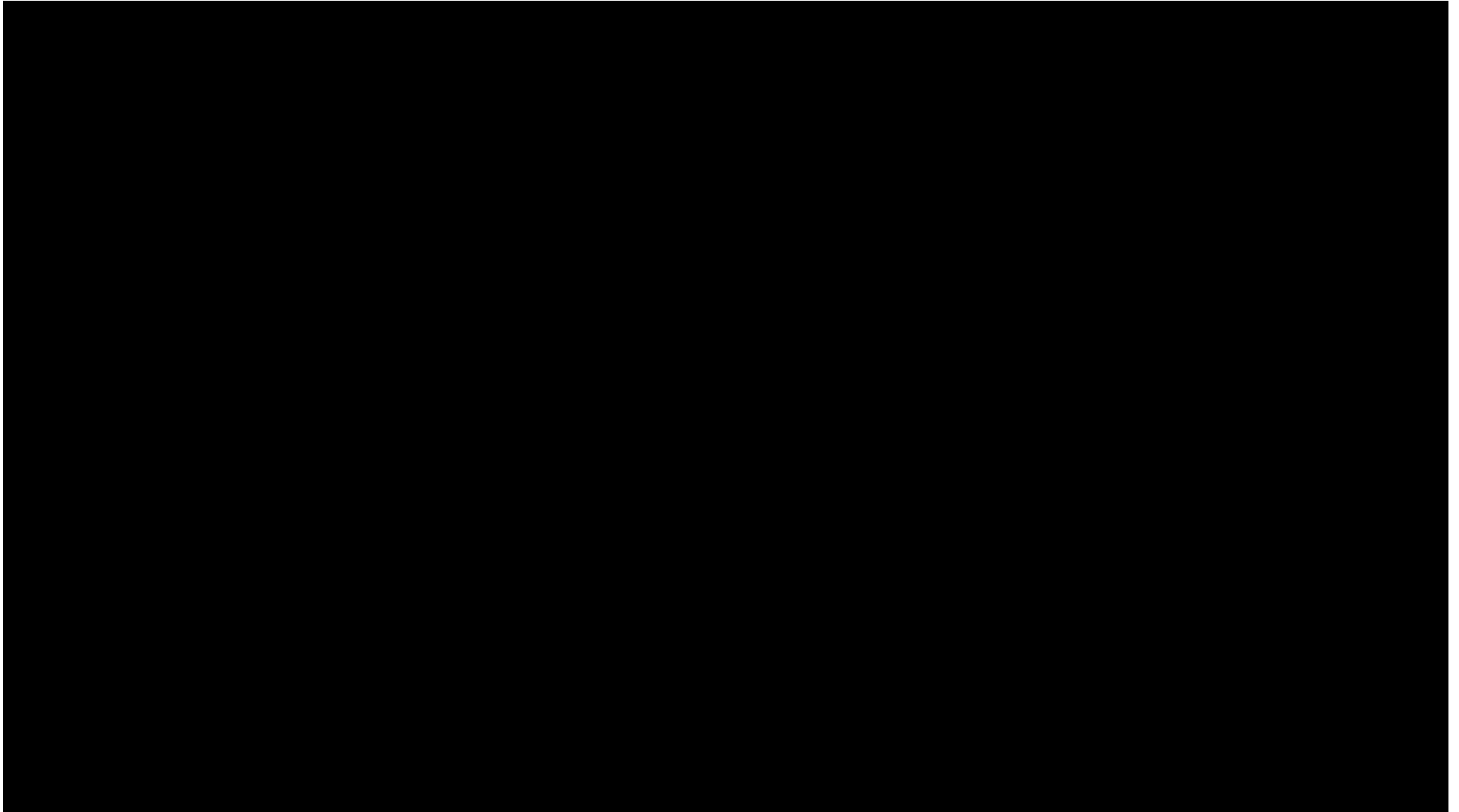
First Humanoid Robot In Space - Hello



First Humanoid Robot In Space – Human Interaction



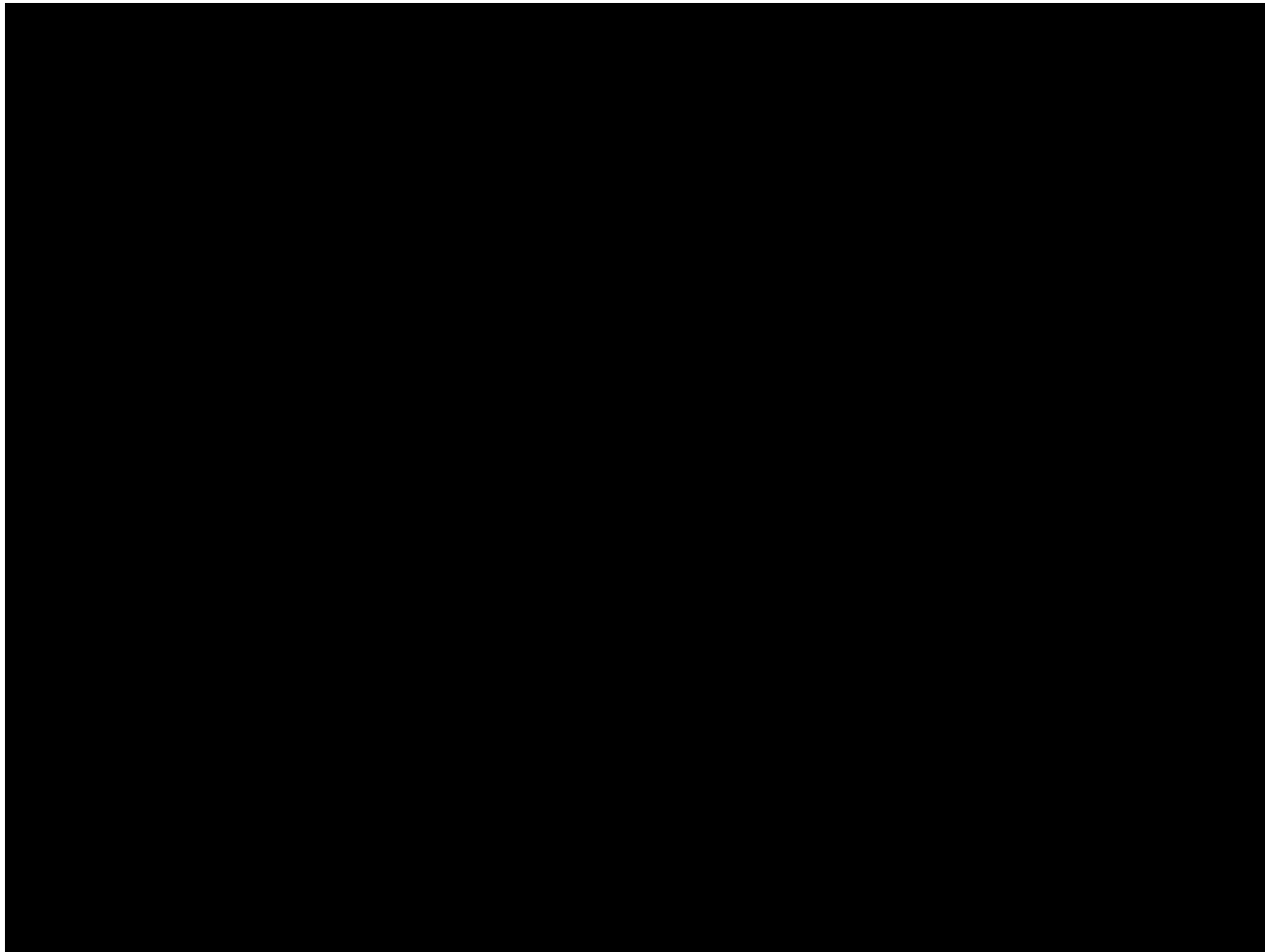
First Humanoid Robot In Space – Power Pane



First Humanoid Robot In Space – Tool Use



First Humanoid Robot In Space – IVA Panel



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IVA Mobility



Need to learn more about climbing in zero-g
ISS IVA is the perfect laboratory

- Buy down risk early

Gain experience for EVA

- Forces
- Gaits
- Ops concepts

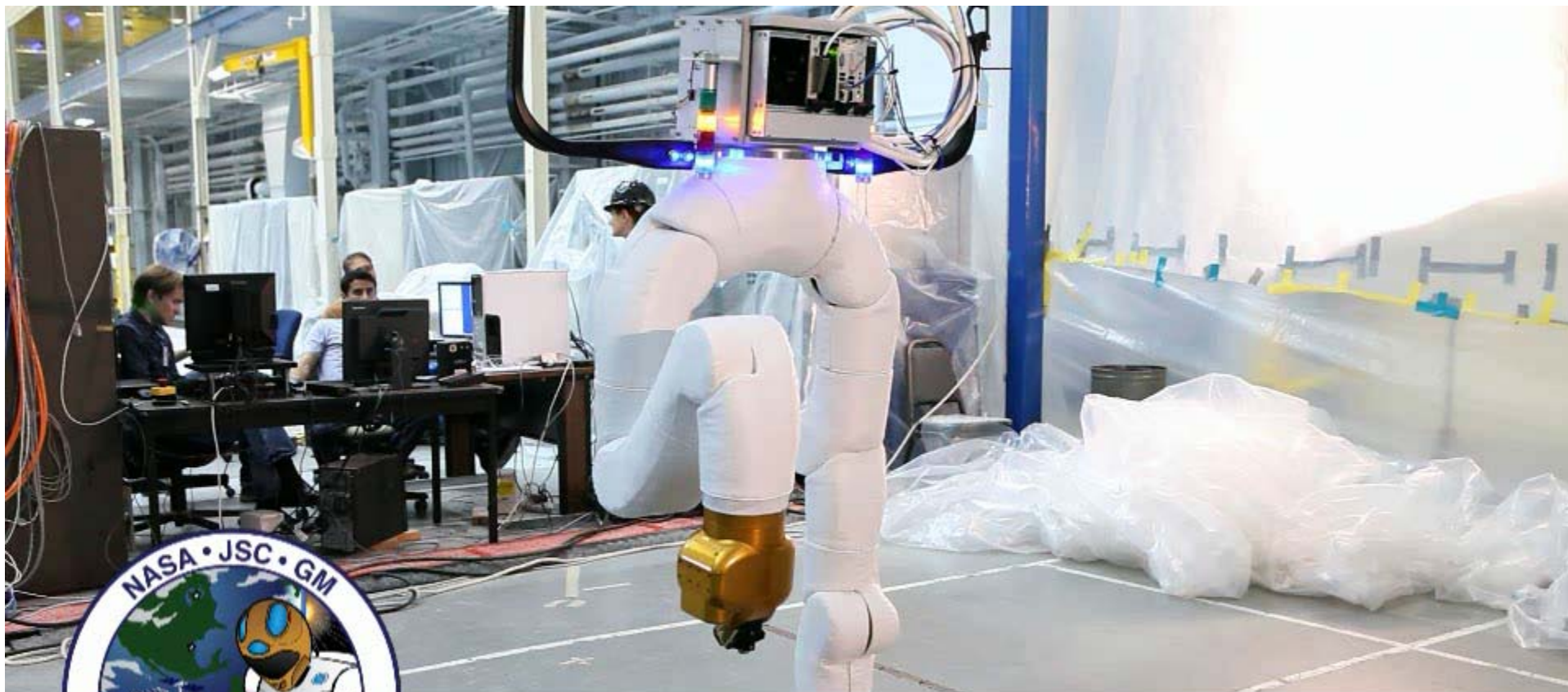
Assist crew with IVA tasks - payoff

- Clean filters
- Inside rack inspection
- Inventory management
- Instrument monitoring
- New tasks are being presented



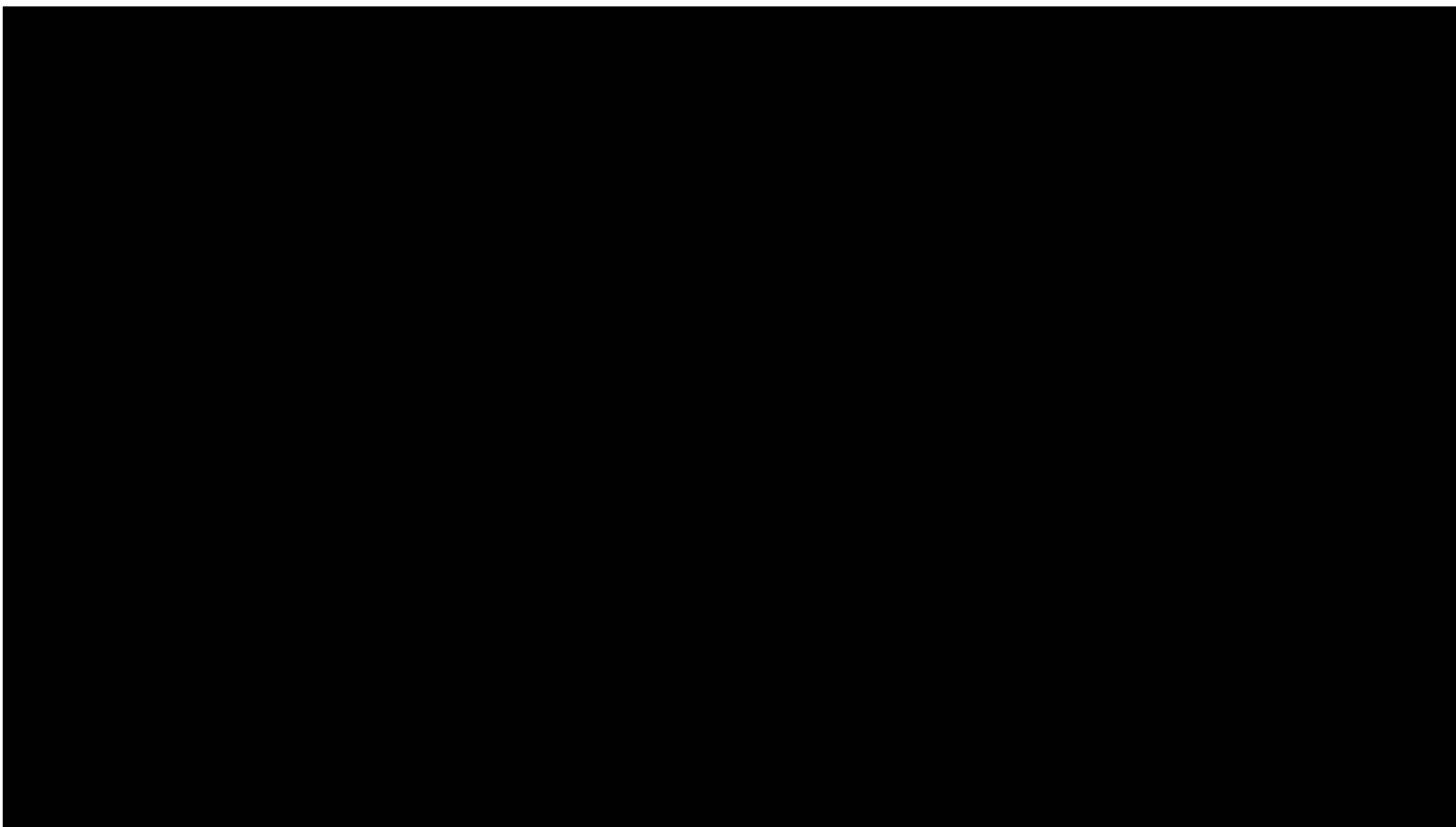
Climbing in ISS

IVA Mobility

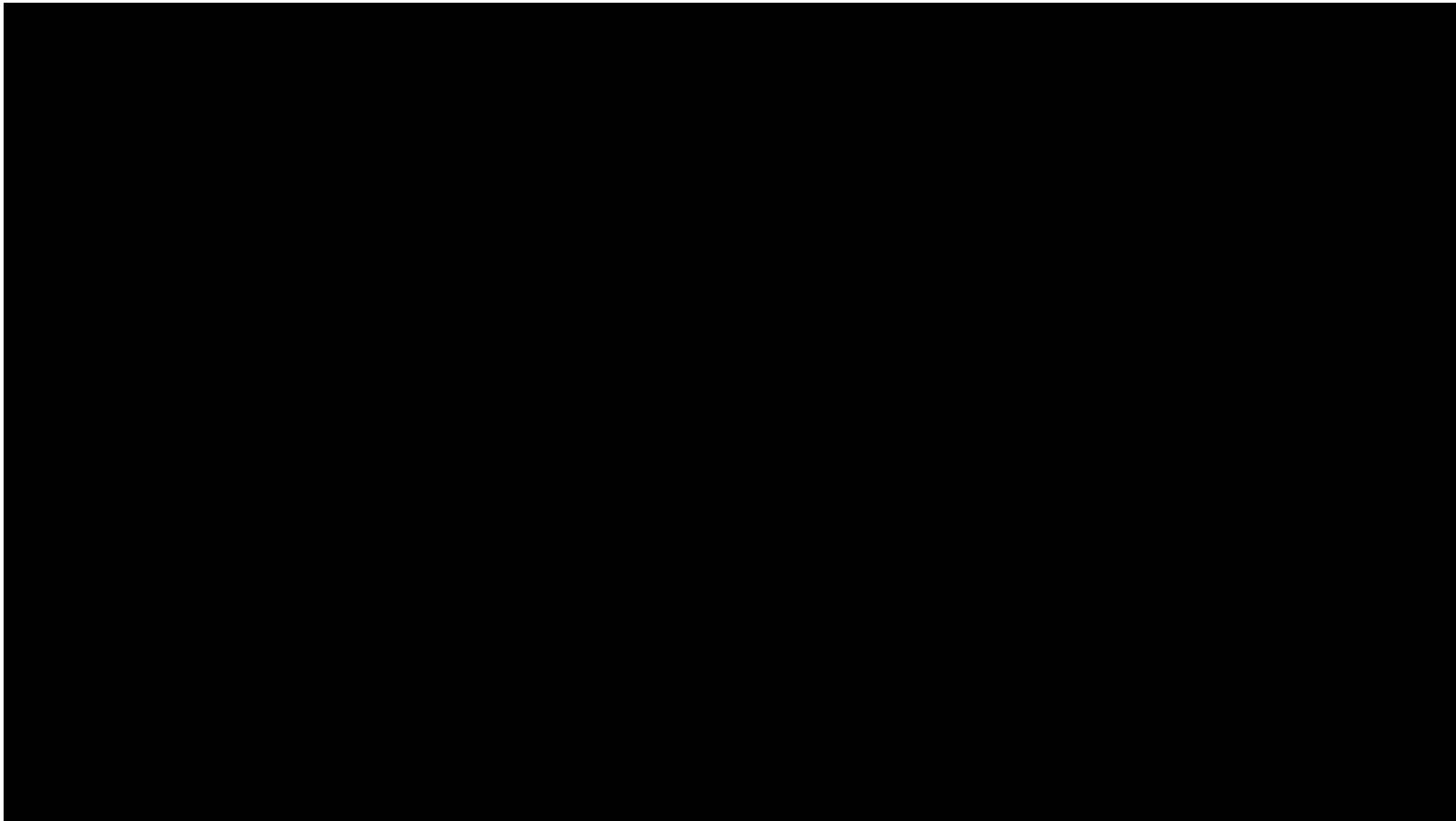


R2 ISS Climbing Legs

IVA Mobility



IVA Mobility –Node Transit



EVA – Big Payoff



Worksite prep/tear down (60-90 minutes on each end)

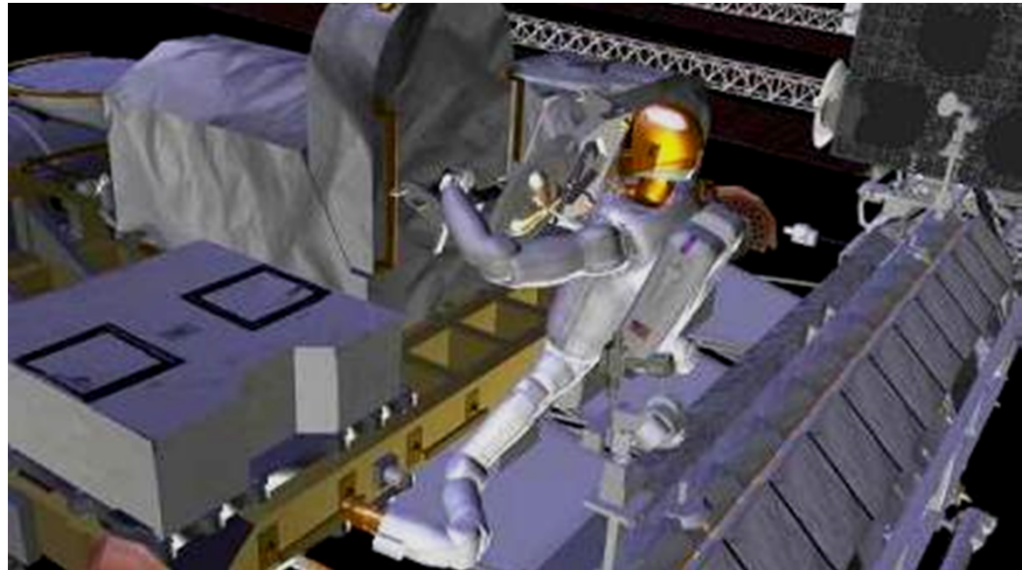
- APFR setup
- Configure EVA Tools
- Retrieve/Stow tools
- Visual inspection under the skin
- Inspection of hoses, flexible lines
- Remove/replace MLI

Assist SPDM

- Remove, replace MLI

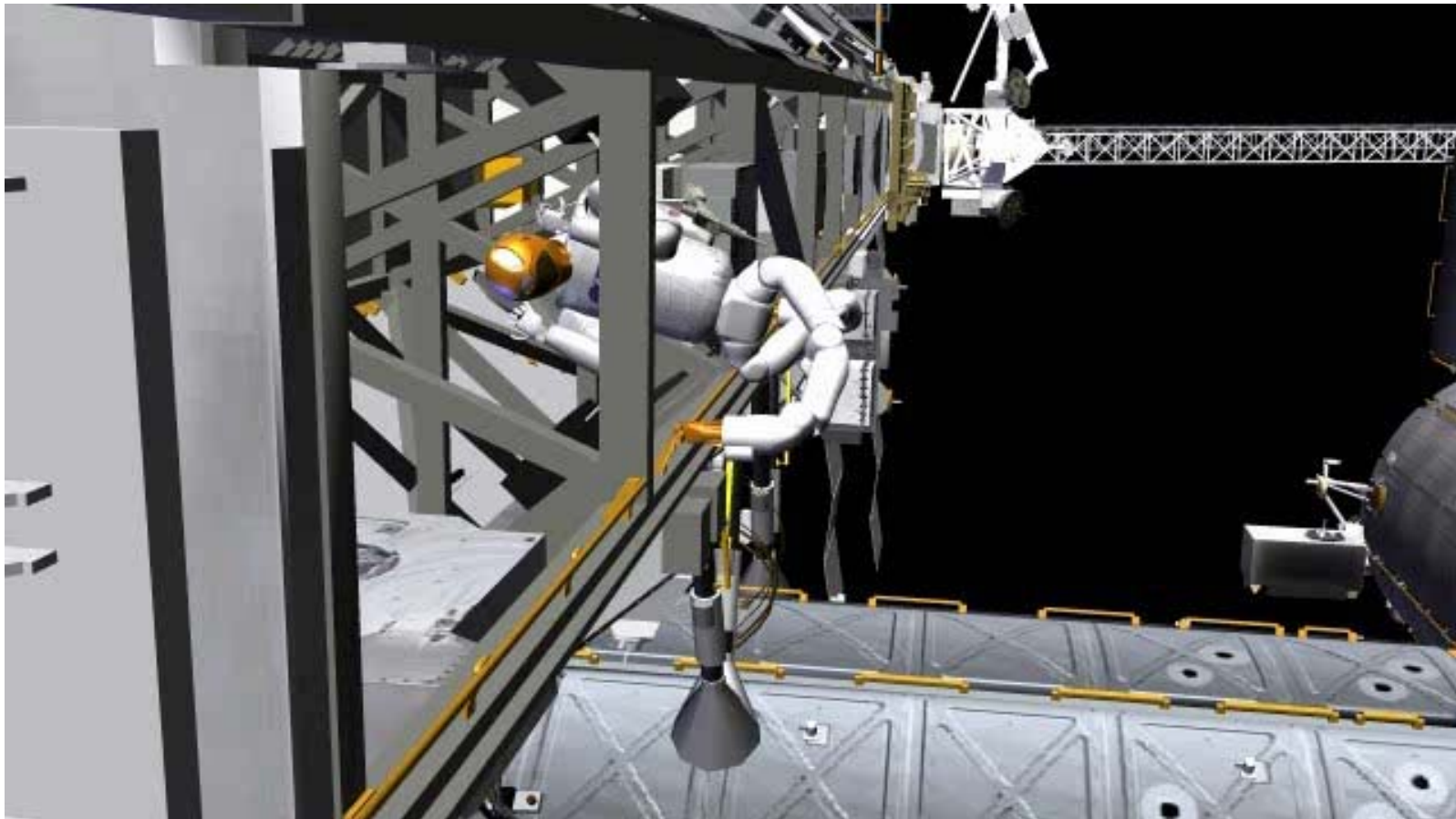
Assist with big 12 tasks

- Work side by side with crew
- Provide temporary fixes
- Perform portions of task



Acquiring Grapple Bar

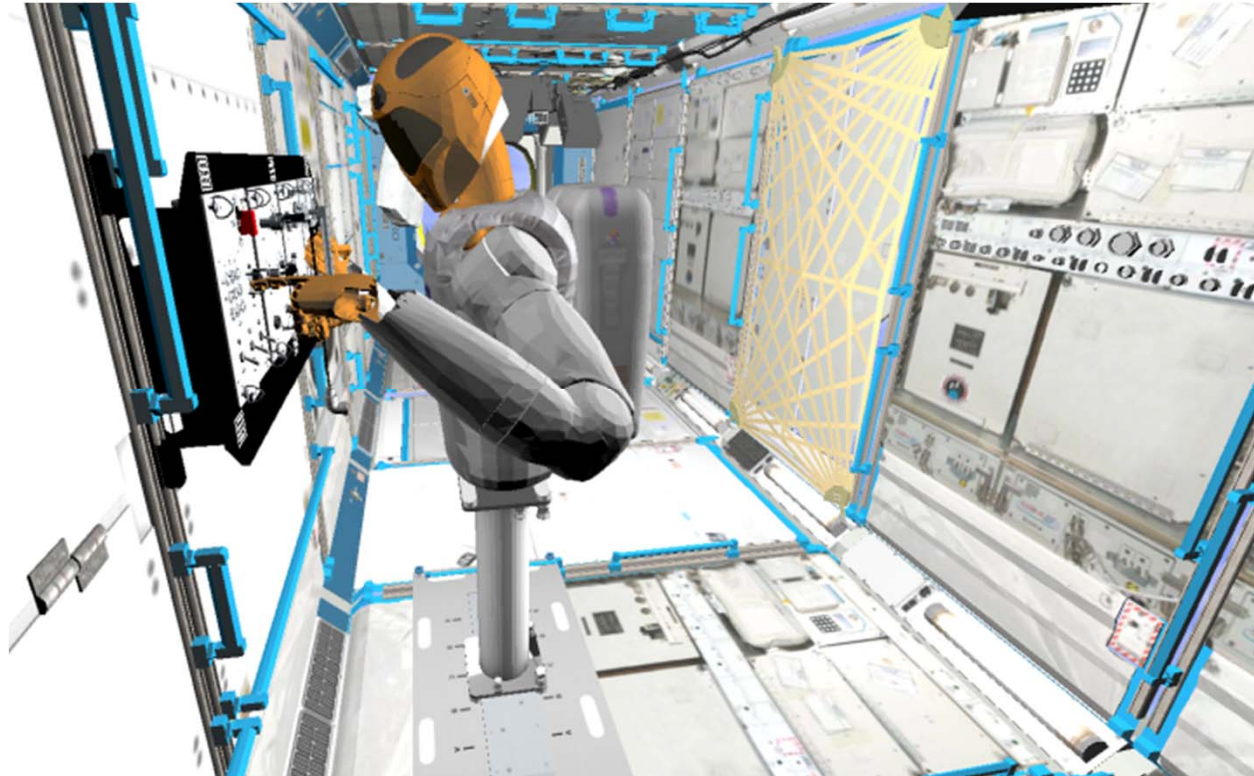
EVA Mobility



Backup



ROS Simulation – Publically Available



Legs Coming Soon

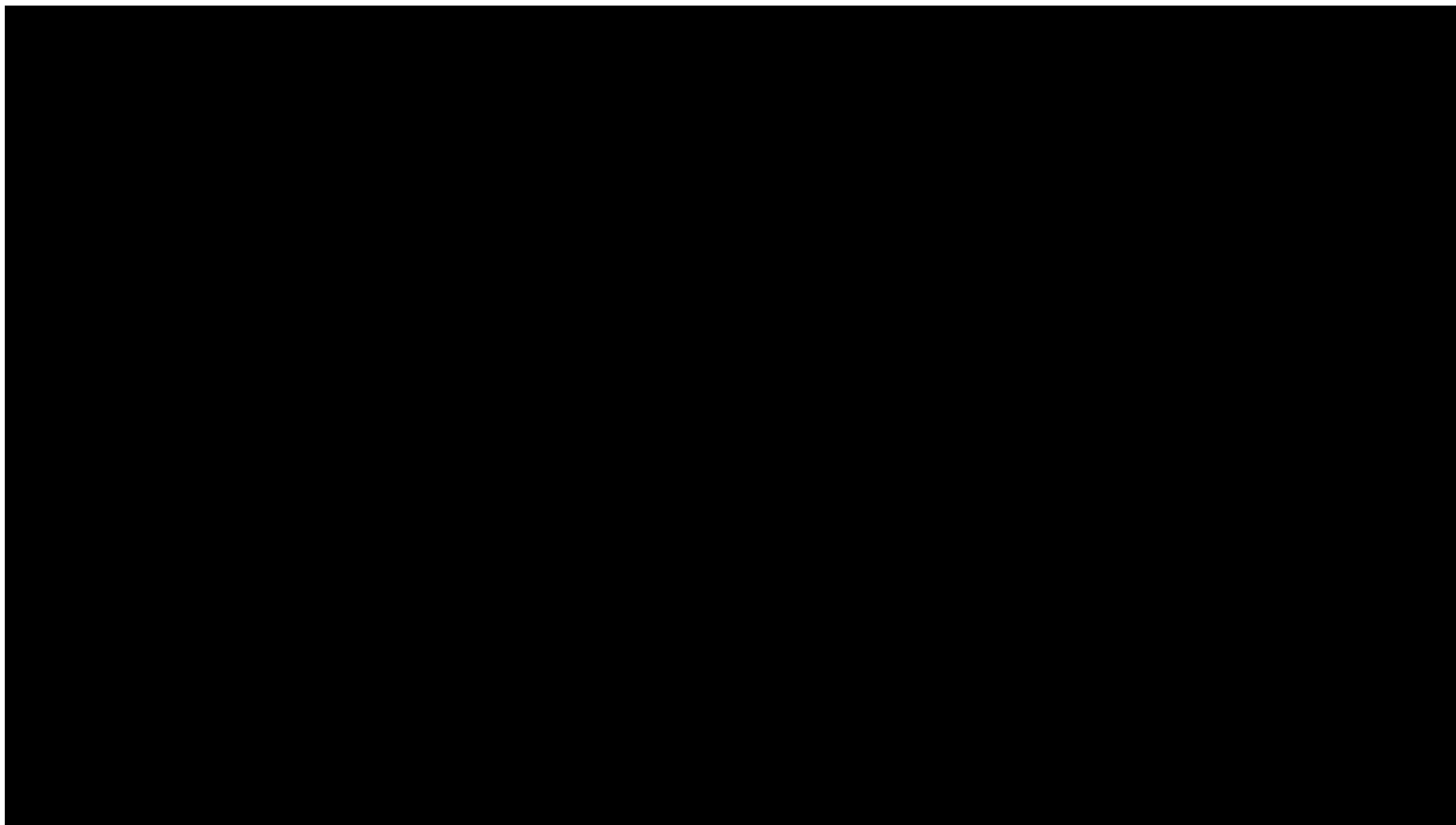
R2 on Space Station



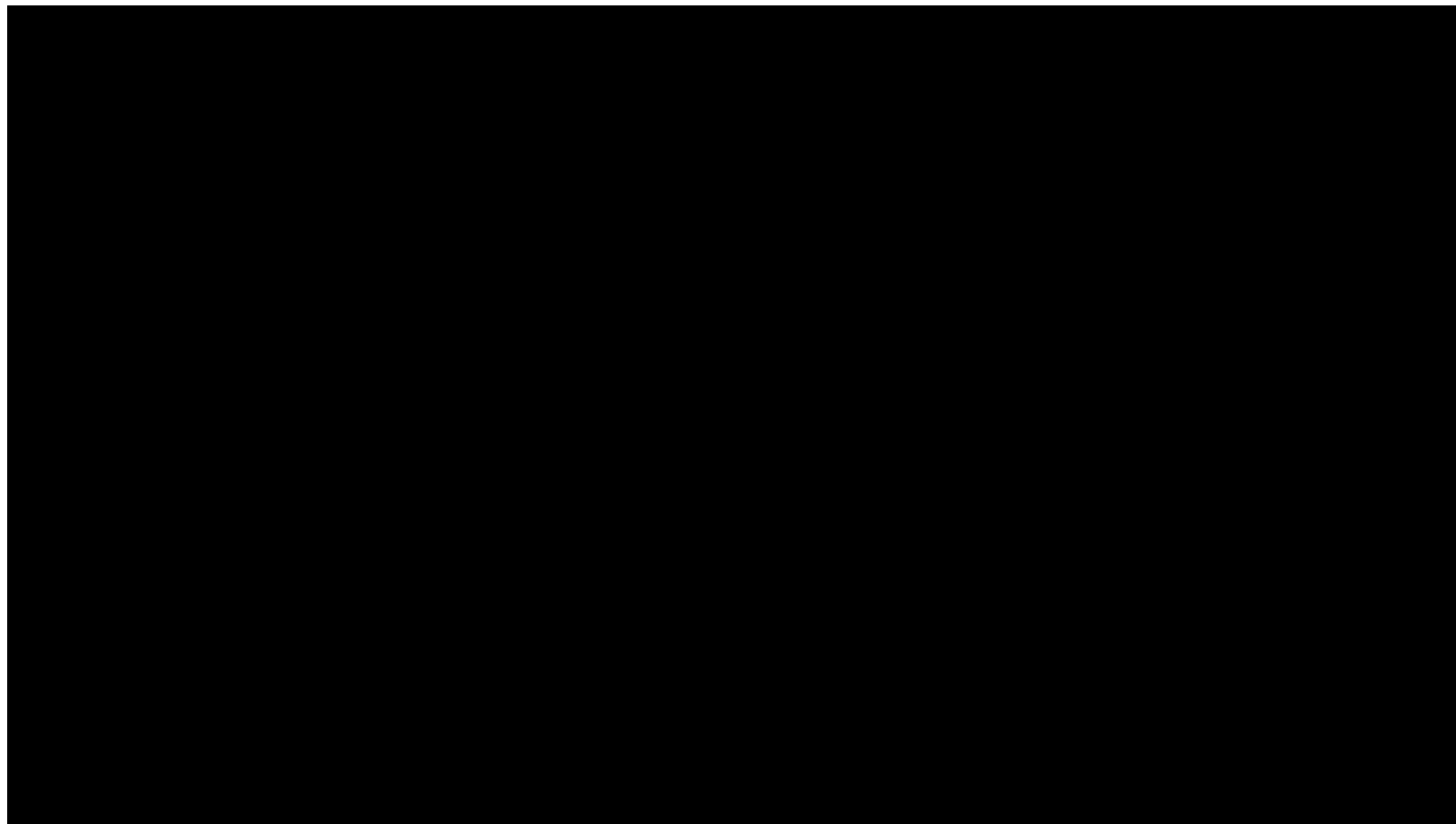
Learn More About R2:
<http://robonaut.jsc.nasa.gov/>



Planetary Capability – Supervised Geologist



Using Tools – Drill Training



Using Tools – Tightening Bolts

